NATIONAL BUREAU OF STANDARDS REPORT

7523

STANDARDIZATION OF THERMAL EMITTANCE MEASUREMENTS

PROGRESS REPORT No. 15

January 1 - March 31, 1962

Contract No. DO (33-616) 61-02

Task No. 73603

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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The two phases of this project are conducted under the supervision of the following persons, who have approved this project.

Horace M. Joseph Horace M. Joseph
Electronic Engineer, Data Processing Systems Division

W N Harrison William N. Harrison - Coordinator
Chief, Metallic Building Materials Section, Buildings Research Division

to
AERONAUTICAL SYSTEMS DIVISION
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NOTICES

I. SUMMARY

The work of preparing and calibrating working standards of normal spectral emittance is proceeding, with no serious hindrance.

The data-processing equipment was delivered and installed. Several minor malfunctions were discovered, and some of them have been corrected. The task of correcting the remaining deficiencies is continuing, and proposed modifications offer promise of providing the means whereby the equipment will meet the design specifications.

II. INSTRUMENTATION

A. Normal Spectral Emittance Equipment

Two new photomultiplier detectors for use in the short wavelength portion of the spectrum were received during the quarter. These are identified by the manufacturer as types 9528B and 9529B. These tubes have been reported to have adequate sensitivity over the spectral range of 0.3 to 1.0 microns. The voltage divider and amplifier modifications required to use the 2529B tube were designed and constructed.

An indium antimonide detector was procured. This detector is reported by the manufacturer to have a usable spectral range of 0.6 to 7.6 microns. Preliminary tests have indicated that this detector does not have sufficient sensitivity for use with the equipment at hand.

The necessary changes in the amplifier circuits were made, and the data-recording and processing attachment was connected to the spectral-emittance equipment.

III. CALIBRATION OF WORKING STANDARDS

A. Oxidized Inconel Specimens

Inconel specimens were prepared for use as working standards of normal spectral emittance. The specimens were machined from 0.053 inch Inconel sheet, and were cleaned with acetone to remove any oil or grease from the machining operation. They were then marked for identification, and sandblasted with 60-mesh fused alumina grit at an air pressure of approximately 70 psi. They were cleaned ultrasonically in acetone, passivated for one minute in 10% nitric acid at 316°K (110°F), rinsed in distilled water, and then acetone. They were placed in a cold furnace, which was brought to 1340°K and held for 24 hours; the temperature was then reduced to 1100°K and held for 24 hours, after which the specimens were allowed to cool in the furnace.

About half of the measurements required in calibrating the Inconel specimens were completed during the quarter.

B. Oxidized Kanthal Specimens

The search for a suitable material from which to prepare working standards of intermediate spectral emittance, and the treatment and testing of specimens to determine their stability, has been described in several previous reports. During this report period, Kanthal that had been polished and then oxidized was rejected as unsuitable for this purpose. It was found that the oxide layer chipped from such specimens after heating in air for periods of 600 hours or more, and that the interference peaks mentioned in previous reports shifted to longer wavelengths with continued heating of the specimens in air.

On the other hand, the spectral emittance curves of Kanthal that had been sandblasted prior to oxidation did not exhibit the interference peaks found with the pre-polished specimens, and the oxide did not chip from the sandblasted specimens that were heated for up to 800 hours at 1300°K. Specimens that had been oxidized for periods of 400, 600 and 800 hours, respectively, showed differences in emittance of less than $\pm$ 0.03, and no consistent trend of spectral emittance with time between 400 and 800 hours of heating in air was observed. In view of these facts, sandblasted Kanthal that had been oxidized for 400 hours at 1300°K was selected for use as the working standard of intermediate emittance. Specimens of the various sizes and shapes required were prepared, by the same procedure as that outlined above for Inconel.

IV. DATA-PROCESSING EQUIPMENT

The data-processing attachment was delivered on February 12, and was installed by a representative of the manufacturer. Fig. 1 is a photograph of the installed equipment.

A. Principles of Operation

The data-processing equipment was designed to perform the following functions: (1) to produce a corrected graphical record of the normal spectral emittance of a specimen as a function of wavelength, (2) to record in digital form on punched paper tape the corrected spectral emittance values, for possible use in a separate electronic digital computer, and (3) to accumulate the digitalized emittances at wavelengths which have been preselected to yield specific information as described further in this report.

The direct input to the data-processing attachment, in the form of electrical potential, is proportional to the apparent emittance of the specimen; that is, the emittance that would be recorded by the spectrometer without benefit of the data-processing attachment. This signal is corrected for systematic instrumental deviations on the basis of previous calibration tests. The resulting record tends to be systematically correct, with only random instrumentation and digitalization errors remaining.

The spectrometer generates two d.c. potentials, one, I_c, proportional to the flux reaching the detector by way of the comparison (blackbody) beam, and the other, I_s, proportional to the flux reaching the detector by way of the specimen beam. The apparent emittance is the ratio of the latter potential to the former. When the instrument is operated with the Function Selector Switch in the "bypass" position (see figure 2), thus bypassing the data-processing attachment, the ratio is measured by applying the I_c potential to the slidewire of a potentiometer recorder, and balancing the I_s potential against the potential of the potentiometer arm. The I_s potential is recorded on the chart as a decimal fraction of the I_c potential, representing the apparent (uncorrected) emittance as a function of wavelength.

However, the optical paths of the two beams in the spectrometer are not quite identical, and somewhat different fractions of the flux in the two beams are measured. This condition is compensated by the data-processing attachment, as described below.

The position of the recording potentiometer arm is digitalized by an encoder which is actuated by the arm shaft. The encoder comprises two axially centered discs, one stationary and one shaft-mounted. Each disc is made of transparent material, to which curved, but nearly radial, opaque stripes of a black coating have been applied. A source supplies light which is alternately passed and blocked as the movable disc rotates. This light is sensed by photoelectric cells, so placed that one cell receives light first when the movable disc is rotated in the clockwise or "upward" direction, and the other cell receives light first when the direction of rotation is reversed. A directional flip-flop is operated by the pulse from the cell first detecting light. A pulse is produced for each increment of rotation corresponding to 0.1 scale division on the chart, or 0.001 in emittance. The pulses are counted in a reversible counter that is gated so that it increases in count when actuated by pulses received in the forward direction of the flip-flop, and decreases in count when actuated by pulses received in the opposite direction. The drum dial position, which determines the position of the Littrow mirror and hence the wavelength of the radiant flux being measured, is also digitalized in the same manner and the resulting pulses are counted. This dial is driven by a synchronous motor. Since the magnetic tape in the tape recorder is likewise driven by a synchronous motor, the two speeds also are synchronous. The tape is a 16-mm wide, four-channel type, perforated along one side and driven by a sprocketed capstan to prevent slippage.

One source of error in the apparent emittance values is deviations in the "100% line", which result from differences in loss of effective flux along the two optical paths. A second source is deviations in the "zero line", due to stray radiation in the monochromator, which produces a spurious I_s signal when there is in fact no flux in the specimen beam.

To correct the deviations in the 100% line, the reference blackbody furnace is substituted for the specimen, and its apparent spectral emittance is recorded with the equipment connected as indicated by the block diagram, figure 3. The data-processing equipment records the pulses from the potentiometer shaft encoder on two channels of the magnetic tape, the pulses in the "upward" direction on one channel, and those in the "downward" direction on the other. Only the change in position of the potentiometer, not the position itself, is recorded. For this reason it is necessary to note and record the reading on the potentiometer at the start of the 100%-line calibration.

The same procedure is used to record the zero-line deviations on another pair of magnetic tape channels, except that the specimen beam is blocked near the specimen furnace. The initial value must also be noted and recorded, as in the case of the "100% line."

When a specimen is under test, each digitalized value of apparent emittance is corrected automatically for deviations in the 100% line and the zero line, respectively. The correction for the former is made by feeding the I_c potential to the 100%-line potentiometer, connected as indicated in figure 4. The arm of this potentiometer is driven by a ratchet motor, actuated by two monostable multivibrator circuits, one for each direction of rotation. During the determination, the previously recorded magnetic calibration tape is played back synchronously with the wavelength drive, the pulses from the upward channel driving the arm of the potentiometer upward, by increments of 0.1%, and the pulses from the downward channel driving it downward an equal amount. The 100%-line potentiometer has the same overall resistance as the recorder potentiometer (468Ω). Before the spectrometer is started, the 100%-line potentiometer is set to the value that was recorded at the start of the 100%-line calibration. The 100%-line potentiometer, as controlled by the magnetic tape during playback, modifies the I_c signal to a value representing the I_r signal at the same wavelength that was recorded during the 100%-line calibration. This modified potential is applied, through an isolating unity-gain amplifier, to the high-voltage end of the slide wire of the recorder potentiometer. Thus the ratio measured by this potentiometer is I_s/I_r, a value which has been corrected for the "100%-line error."

The zero-line correction is made through a similar zero-line potentiometer, connected as shown in figure 5, and driven by a similar ratchet motor and multivibrator circuits, actuated by pulses from the zero-line channels on the magnetic tape. The zero-line potentiometer also is set at the value that was recorded at the start of the zero-line calibration before starting the spectrometer. The zero-line potentiometer, as controlled by the magnetic tape during playback, produces a signal representing the I_o signal at the same wavelength that was recorded during the zero-line calibration. This signal is applied, through a similar isolating unity-gain amplifier, to the low-voltage end of the slidewire of the recorder potentiometer, maintaining it above ground potential. The net effect of this adjustment is to subtract this zero-line potential from both the corrected I_c ($=I_r$) potential and the I_s input potential, thus compensating for the zero-line error.

The potentials from the 100%-line and zero-line potentiometers are applied to the recorder potentiometer through isolating unity-gain amplifiers to prevent reduction in potential due to load. A block diagram of the equipment during a specimen run is shown in figure 6.

Figure 7 is a photograph of a portion of a recorder chart, showing the recorded "100% line", "specimen line" and "zero line." In manually computing the emittance of a specimen at any wavelength from such a chart, the height of a "specimen line" above the "zero line", designated AE_s on the chart, is divided by the height of the "100% line" above the "zero line", designated as the distance AE_{BB} on the chart. This computation is repeated at each wavelength of interest, usually at 100 points in the wavelength range of 1 to 15 microns. The pips in the lines on the chart are wavelength markers, and occur at each 0.1 revolution of the wavelength drum (hence do not represent equal wavelength intervals). An extra pip appears at 0.95 revolution of the drum to identify the number of revolutions.

B. Mathematical Analysis of Operation

The operation of the data-processing equipment may be analyzed mathematically as follows:

Let I_c = comparison blackbody signal
I_r = reference blackbody signal
I_o = zero signal (spurious signal received when specimen beam is blocked)
I_s = specimen signal
W_B = radiant flux from blackbody entering the optical system to produce I_c or I_r. (The flux from the reference and the comparison blackbody furnaces is equal since they are at the same temperature.)
W_s = radiant flux from specimen entering the optical system to produce I_s.

Note: All of the signals, I_c, I_r, I_o and I_s, appear as potentials in the output of the spectrometer amplifier, before entry into the potentiometer recorder or data-processing attachment.

a = proportionality factor between flux entering specimen beam of spectrometer and signal produced; $W_B = a\ I_r$, $W_s = a\ I_s$.

Note: All of the above terms are functions of wavelength, λ, and all are referred to at a specific value of λ, but for simplicity, the subscript λ is omitted in the mathematical treatment that follows.

Let us first consider what is needed, in terms of signals, to give the true emittance of the specimen. The zero signal, I_o, is measured only in the specimen beam of the spectrometer and is assumed to have the same spectral distribution for the reference blackbody and for the specimen at the same temperature. Also, the reference blackbody and the specimen are interchanged for measurement in the specimen beam. Therefore, for each wavelength of the specimen beam,

$$W_B = a\,(I_r - I_o) \tag{1}$$

and

$$W_s = a\,(I_s - I_o) \tag{2}$$

Since the spectral emittance, E, is defined as

$$E = W_s/W_B \tag{3}$$

the desired equation, in terms of signals, becomes

$$E = \frac{(I_s - I_o)}{(I_r - I_o)} \tag{4}$$

The factor a cancels out, and need not be considered further.

However, the spectrometer is used as a double-beam instrument, which measures the ratio of the signal from the specimen beam to that in the comparison blackbody beam, and we must work with these instrumentally obtained ratios to obtain the desired corrected emittance values.

First, assume that $I_o = 0$. Then, from equation (4),

$$E = I_s/I_r \tag{5}$$

The output of the spectrometer is the position of the recording potentiometer arm, which represents the ratio of the signals from the respective beams in terms of the fraction, f, of the total range of the arm. This fraction, f, may also be recorded on a strip chart as a decimal fraction.

During calibration, see figure 3, the two signals are I_c in the comparison beam and I_r in the specimen beam. Consequently,

$$f' = \frac{I_r}{I_c} \tag{6}$$

This ratio, f', is recorded as the "100% line" on the magnetic tape, and may also be recorded on the chart, during the 100% calibration. During the testing of a specimen, in which the automatic data-processing attachment functions to make automatic corrections, the playback from the magnetic tape controls the position of the arm on the 100%-line potentiometer in the attachment to the fraction, f', of its range, while the potential applied to its slidewire is the signal I_c. Hence the output of the 100%-line potentiometer is

$$f'I_c = I_c \cdot \frac{I_r}{I_c} = I_r \qquad (7)$$

which is applied to the recording potentiometer slidewire by the amplifier. The signal input is I_s, and for this condition

$$f'' = I_s/I_r \qquad (8)$$

the corrected spectral emittance, for $I_o = 0$.

The situation is more complex when $I_o > 0$, as it usually is. In figure 5, the potential from the 100%-line potentiometer, which was shown in equation (7) to be equal to I_r, is applied to the top end of the recording potentiometer slidewire. The potential from the zero-line potentiometer is applied to the bottom end of the slidewire. This potential is equal to I_o, as is shown by the following treatment.

During zero-line calibration, the position, f''', of the arm on the recording potentiometer is

$$f''' = I_o/I_c \qquad (9)$$

During playback, the position of the arm on the zero-line potentiometer is controlled by the signals from the magnetic tape to the fraction, f''', of its range, while the potential applied to its slidewire is a constant voltage, K, representing I_c. It should be noted that the slit servomechanism of the specrometer automatically opens and closes the slits of the monochromator to keep I_c constant during a test.

The potential drop across the recording potentiometer slidewire is thus $I_r - I_o$. The potention, I_s, is balanced against the arm potential:

$$I_o + f''''(I_r - I_o) = I_s \qquad (10)$$

consequently

$$f'''' = \frac{I_s - I_o}{I_r - I_o} \qquad (11)$$

the spectral emittance corrected for both absorption and stray radiation, see equation (4).

Since equation (11) involves signals from a blackbody furnace and a specimen at the same temperature and at the same source position (the effect of the signal I_c from the comparison blackbody having been cancelled out in derivation of the expression) the proportionality factor, a, is in both numerator and denominator, hence cancels out, as was shown in equation (4).

The emittance, or f'''', appears as a shaft position of the recording arm and pen which is encoded as before. The results are counted in the reversible counter. The positions of the counter are punched in Friden Programmatic Single Case Code on paper tape at preset intervals of drum rotation. The counter numbers are also accumulated in the electronic accumulator, at other preset intervals. The results shown by the recording pen counter, the digitalized drum dial counter, or the accumulator can be selected for display as decimal digits. These digits are punched in a word group whose first four characters are the drum dial division numbers. The latter three are the pen position digits. The most significant digits are first. The eighth character is always a "Carriage Return."

The preset wavelengths for punching and addition are selected separately. These intervals for punching are each

1/2 drum dial division,
1 drum dial division,
2 drum dial divisions
5 drum dial divisions,
or 10 drum dial divisions, as desired.

The increments between successive wavelengths at which spectral emittance values are to be accumulated are pre-recorded on punched paper tape. The tape is read into the data-processing equipment during a determination by the tape reader. The method of coding the tape is explained below.

The theory of the selected ordinate method of computing total emittance, or absorptance for radiation having any known spectral distribution of flux, was explained in WADC Technical Report 59-510. In brief, the total flux from the source (blackbody at the temperature of the specimen for total emittance) is divided into N equal parts, and the wavelengths bracketing the intervals between $\lambda = o$ and $\lambda = \infty$ within which the respective 1/N fractions of the flux lie, are established. The N wavelengths at which the normal spectral emittances are to be accumulated are the median wavelengths of the N intervals. The total normal emittance is then 1/N times the sum of the normal spectral emittances at the N wavelengths.

C. Preparing Punched Paper Tape

Punched paper tape is required to trigger the accumulator to sum the readings of corrected emittance for the purpose of using the selected ordinate method of computing total emittance (or absorptance). It is first necessary to determine the wavelengths at which the accumulation is to be performed, and then to record these values on punched paper tape in the proper manner. The method of selecting the wavelengths was outlined briefly above.

After the proper wavelengths have been selected, they are processed as follows:

1. Convert the selected wavelengths, into wavelength drum positions, by means of a calibration curve, to the nearest 0.2 dimension on the scale (1/500 of a revolution of the wavelength drum).

2. Compute the increments between successive wavelength drum positions, in units of scale divisions and fractions.

3. Multiply the increments by 5, to get them into integral numbers of 1/5 scale divisions.

Note: The first increment is that between the starting position of the wavelength drum and the position corresponding to the first preselected wavelength.

4. Convert the integral decimal numbers obtained in 3 to three-digit, hexa-decimal numbers; i.e., base 16 numbers. The digits in this system are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F. The number 108_{10} then becomes $06C_{16}$, or 3118_{10} becomes $C2E_{16}$.

5. Form the F complement of these numbers, i. e., subtract the number from FFF. Thus $108_{10} = 06C_{16}$ becomes $F93_{16}$, and $3118_{10} = C2E_{16}$ becomes $3D1_{16}$. (An alternative procedure is to subtract the original number in decimal form from 4095, and convert the difference to hexa-decimal numbers. Thus for 108_{10}

$$4095_{10} - 108_{10} = 3987_{10} = F93_{16}$$

and for 3118_{10}

$$4095_{10} - 3118_{10} = 977_{10} = 3D1_{16}.)$$

6. Prepare a 9-channel punched paper tape in word groups of 4 characters each. The first character of the word is a Carriage Return and the following one is the least significant digit of the hexadecimal number, followed by the middle digit, followed by the most significant digit. For the two examples, one would type for 108_{10}

$$\begin{matrix} C \\ R \end{matrix}\ 39F$$

and for 3118_{10}

$$\begin{matrix} C \\ R \end{matrix}\ 1D3 .$$

For use, the punched paper tape is inserted into the paper tape reader, and the wavelength drum is set to the starting position. The accumulator selector switch is set to the tape reader position, and the tape reader is turned on. As the spectrometer traverses the spectrum, the tape reader will trigger the accumulator circuit each time the wavelength drum has advanced an amount equal to the recorded increment. The paper tape reader automatically advances the tape one position after each accumulation.

D. Current Status

The electronic data-processing equipment was installed during the week following delivery by a representative of the manufacturer. The functions of counting the pulses from the recording potentiometer shaft encoder, and from the accumulator, were each checked and found to operate properly. The calibration tape punch produced the correct numbers. The separate controls for accumulation and punching by fixed increments and by reading from a prepunched tape were checked, and the events occurred at the expected times.

However, the magnetic tape reel held only about 300 feet of tape and the tape drive ran so fast that calibration runs were limited to about 8 minutes, compared to approximately 32 minutes required for a complete traverse from 1 to 15 microns. Although the tape was not long enough to be operationally useful, it could be used in checking the operation of the equipment. Larger reels and a 1200-foot tape were procured for use with the equipment, which permits calibration runs of approximately 32 minutes.

A number of check tests of the equipment were made, and several tapes were punched. One tape was plotted on a digital-type plotter. Intermittent troubles soon appeared, which indicated that reliable results could not be obtained. For instance, the drum dial counter and accumulator did not advance the more significant digits as they should, and the recording potentiometer counter jumped counts abruptly. It was not possible to set the (analog) isolating amplifier input voltage to the proper value when the counters operated properly. Later the punch did not operate.

The manufacturer was informed of these developments, and sent a representative to remedy the difficulties. The tape drive motor was replaced with one operating at half the speed of the original, which increased the time available for calibration runs to about 64 minutes. Diode gates were added to prevent counts from occurring during sign reversal. Some additional grounding was added, but the difficulty of setting the initial voltage of the d.c. isolating amplifiers and their rapid drift after adjustment, and the troubles due to the effect of variable contact resistance in the switches within the signal path have not yet been corrected. The remaining difficulties appear to be comparatively minor in nature, but they prevent obtaining usefully accurate results with the new attachment, prior to their elimination. The manufacturer is aware of these troubles, and has agreed to correct them in the near future.

V. MATHEMATICAL EQUATIONS

In furthering the approach mentioned in the preceding report, namely the assumption that more than one "family" of free electrons governs the emissive properties of platinum within the wavelength range covered by experiments reported herein, additional numerical experiments were carried out during the report period. These experiments indicated that a better fit of the spectral emittance curves could be obtained from the equation (see WADC Tech. Rept. 59-510, Part III, equations 2, 3 and 4) than when only one family of free electrons was considered. An attempt to find the best values of the parameters describing the two free-electron families was begun. Numerical experiments dealing with bound-electron families were continued.

Figure 1. Photograph of the data-processing equipment attached to the spectrometer. The electronic circuits are housed in the chassis above the recorder at the right, and the paper tape punch and punched paper tape reader are on the table at the extreme right.

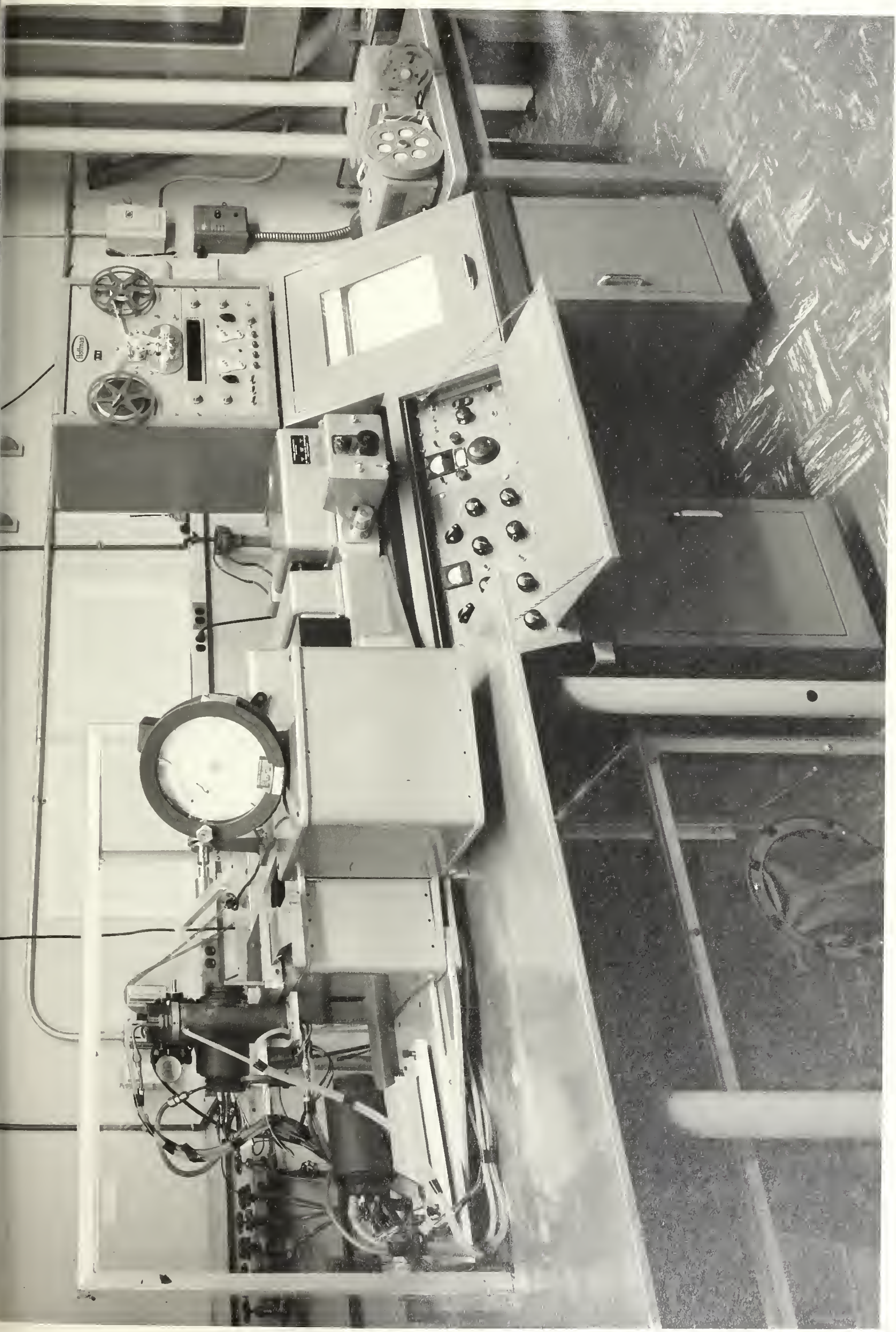
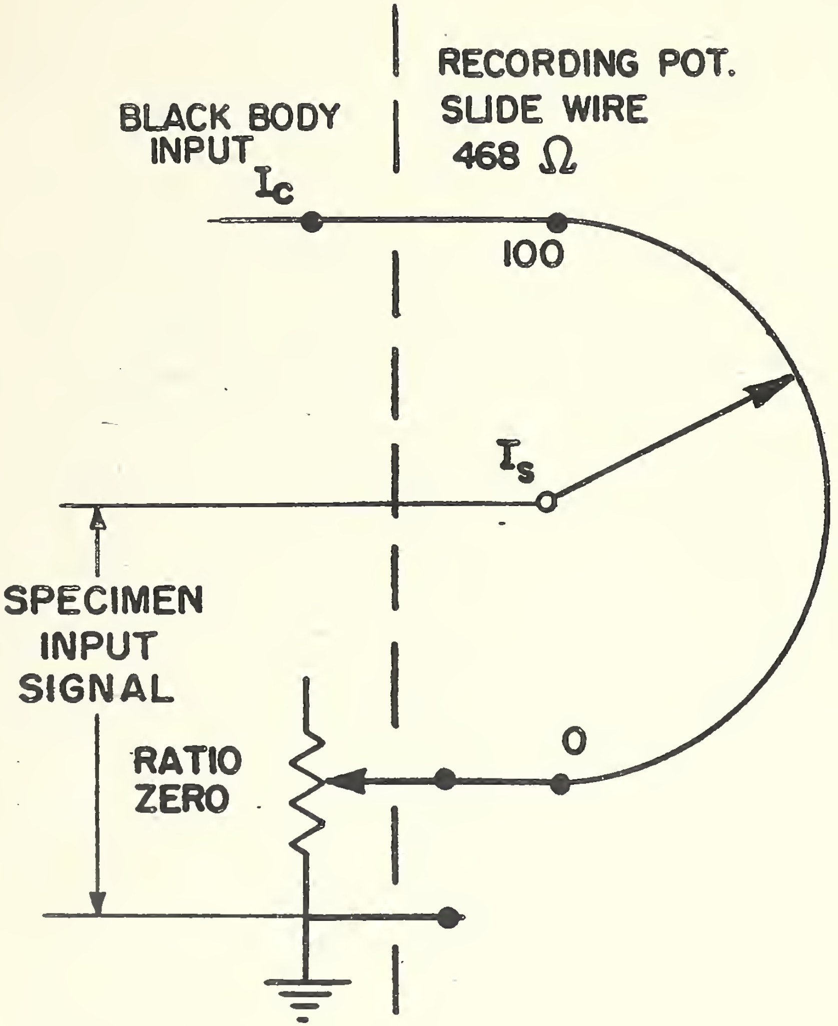
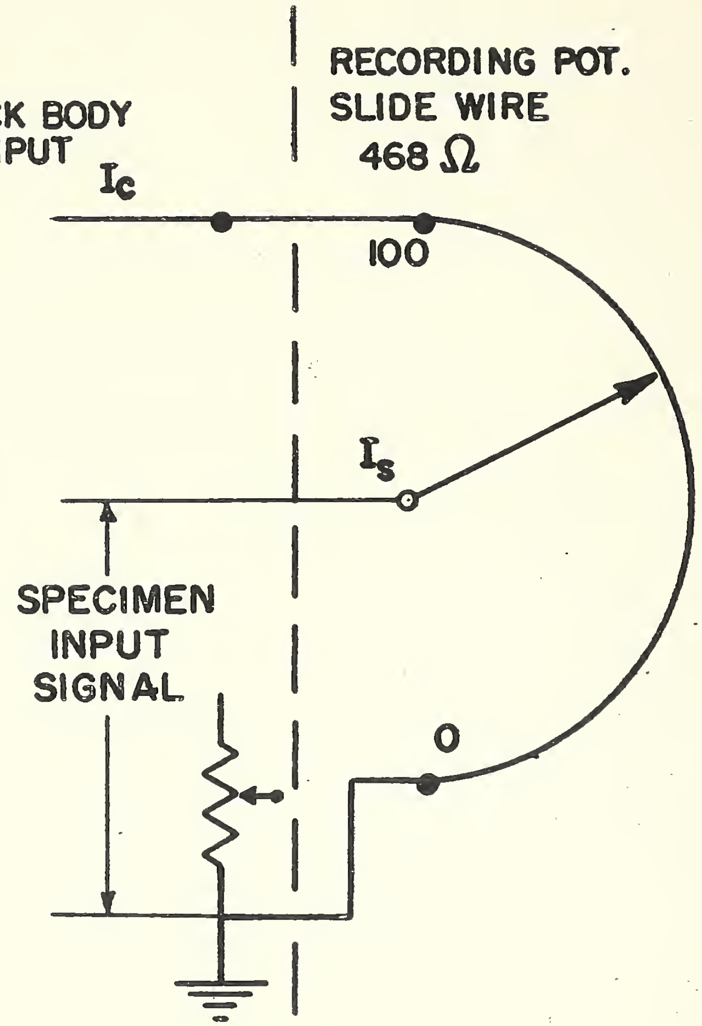


Figure 2. Schematic diagram showing connections through Function Selector Switch in "Bypass" and "Record 100%" and "Record Zero" positions. When this switch is in "Bypass" position, the data-processing equipment is completely inoperative.



(a)

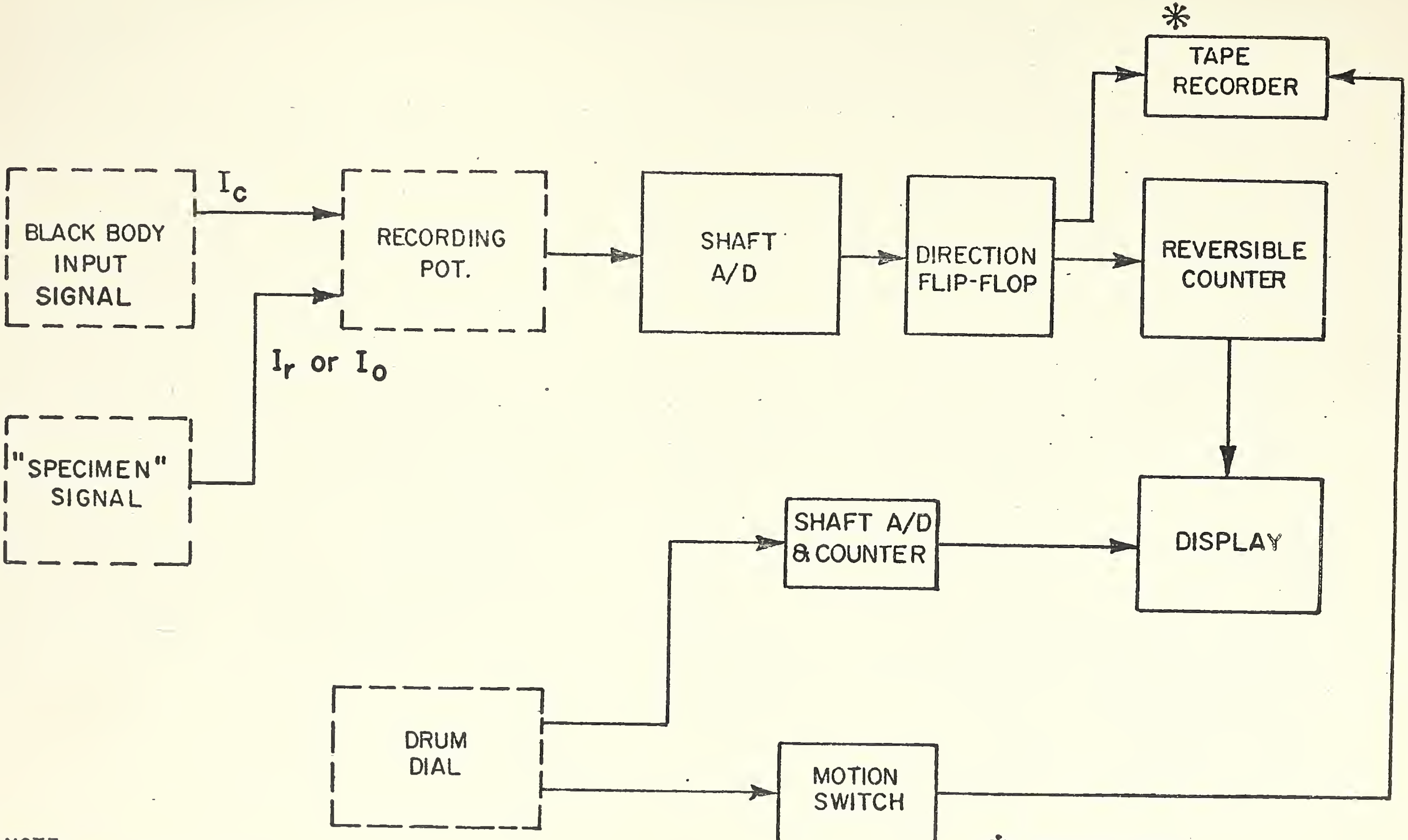
BYPASS



(b)

RECORD "100 %" AND "ZERO"

Figure 3. Block diagram of equipment during recording of "100%" and "zero" line deviations.



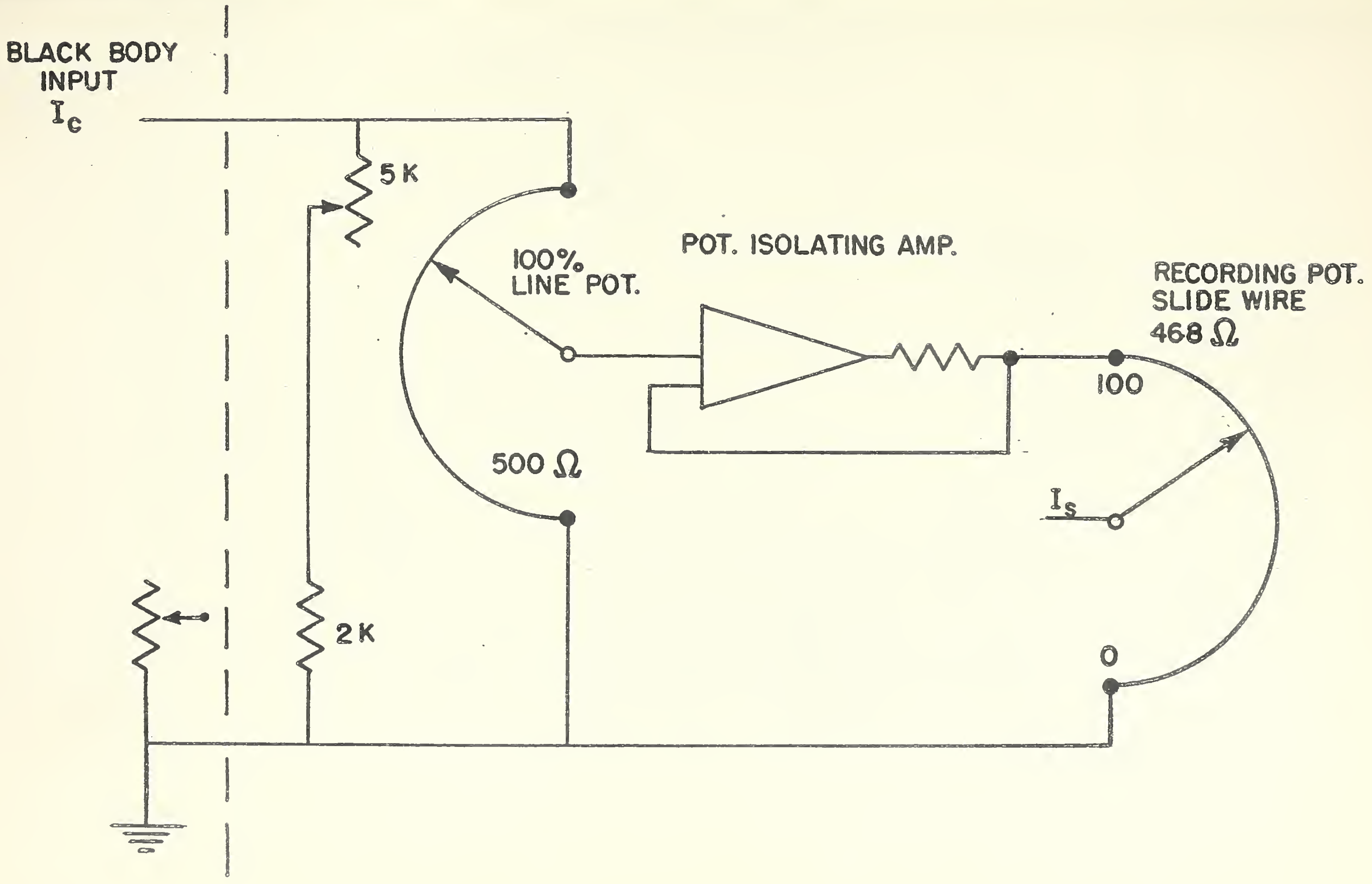
NOTE

DASHED LINES SHOW SPECTROPHOTOMETER

* FOUR TRACKS

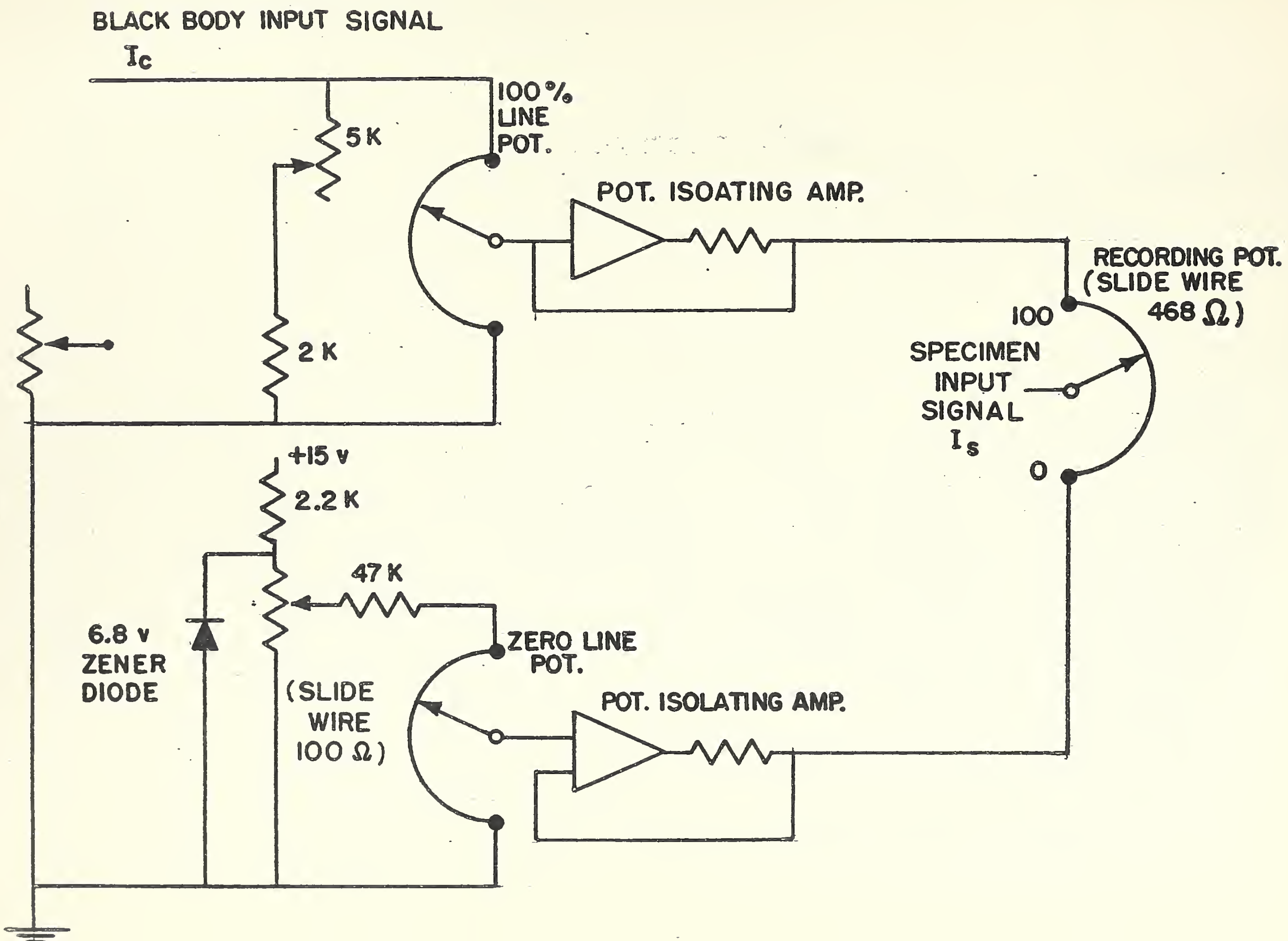
(a.) POSITIVE DIRECTION-100 %
(b.) NEGATIVE DIRECTION- "
(c.) POSITIVE " " -ZERO
(d.) NEGATIVE " " - "

Figure 4. Schematic wiring diagram of potentiometer circuits during playback of "100% line" deviations.



BLACK BODY INPUT
I_c
5 K
2 K
100% LINE POT.
500 Ω
POT. ISOLATING AMP.
RECORDING POT. SLIDE WIRE 468 Ω
100
0
I_s

Figure 5. Schematic wiring diagram of potentiometer circuits during playback of both "100% line" and "zero line" deviations.



BLACK BODY INPUT SIGNAL
I_c
5 K
2 K
100 %
LINE
POT.
POT. ISOATING AMP.
RECORDING POT.
(SLIDE WIRE
468 Ω)
100
SPECIMEN
INPUT
SIGNAL
I_s
0
+15 v
2.2 K
47 K
6.8 v
ZENER
DIODE
(SLIDE
WIRE
100 Ω)
ZERO LINE
POT.
POT. ISOLATING AMP.

Figure 6. Block diagram of data-processing equipment during recording of corrected normal spectral emittance of a specimen.

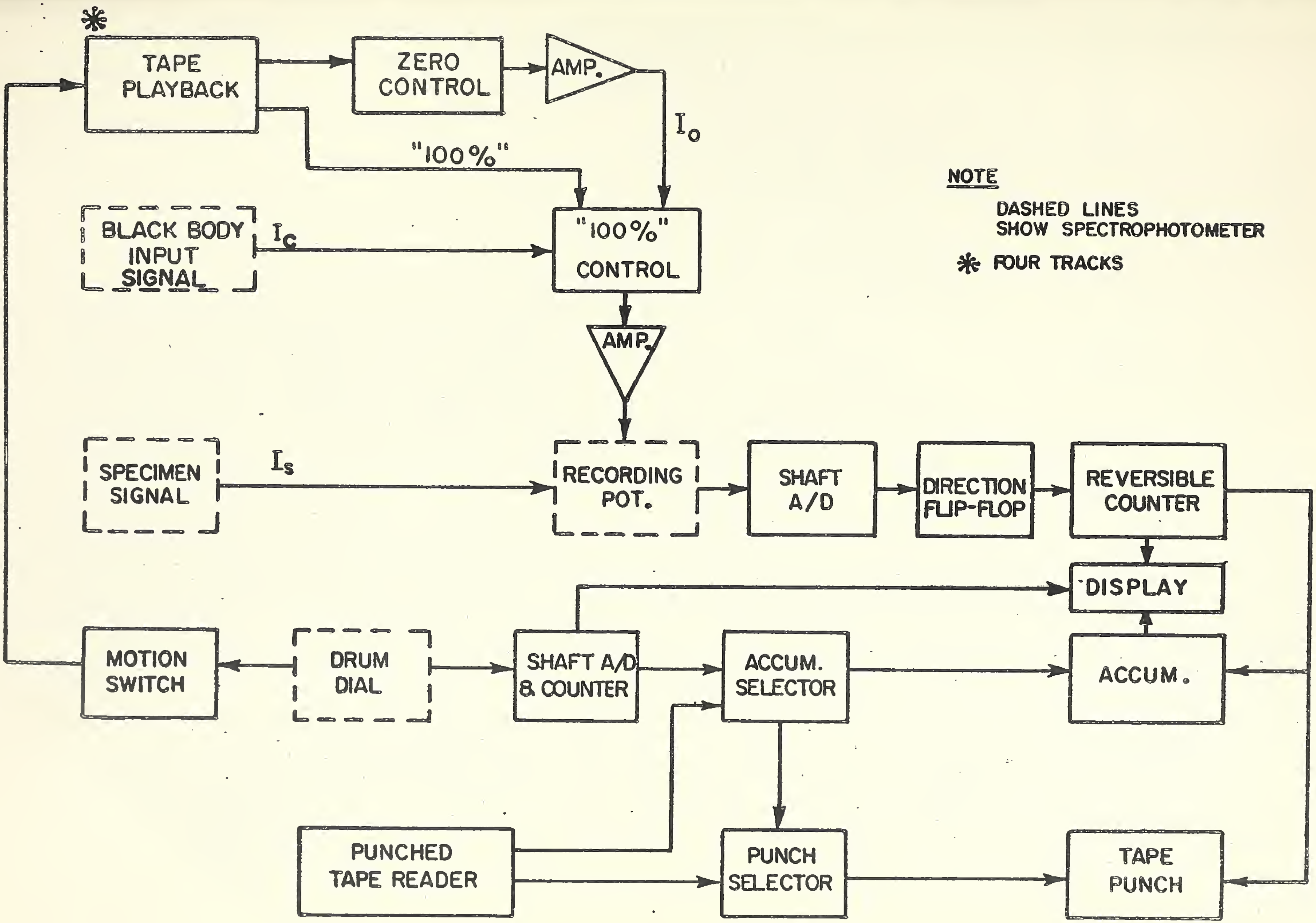
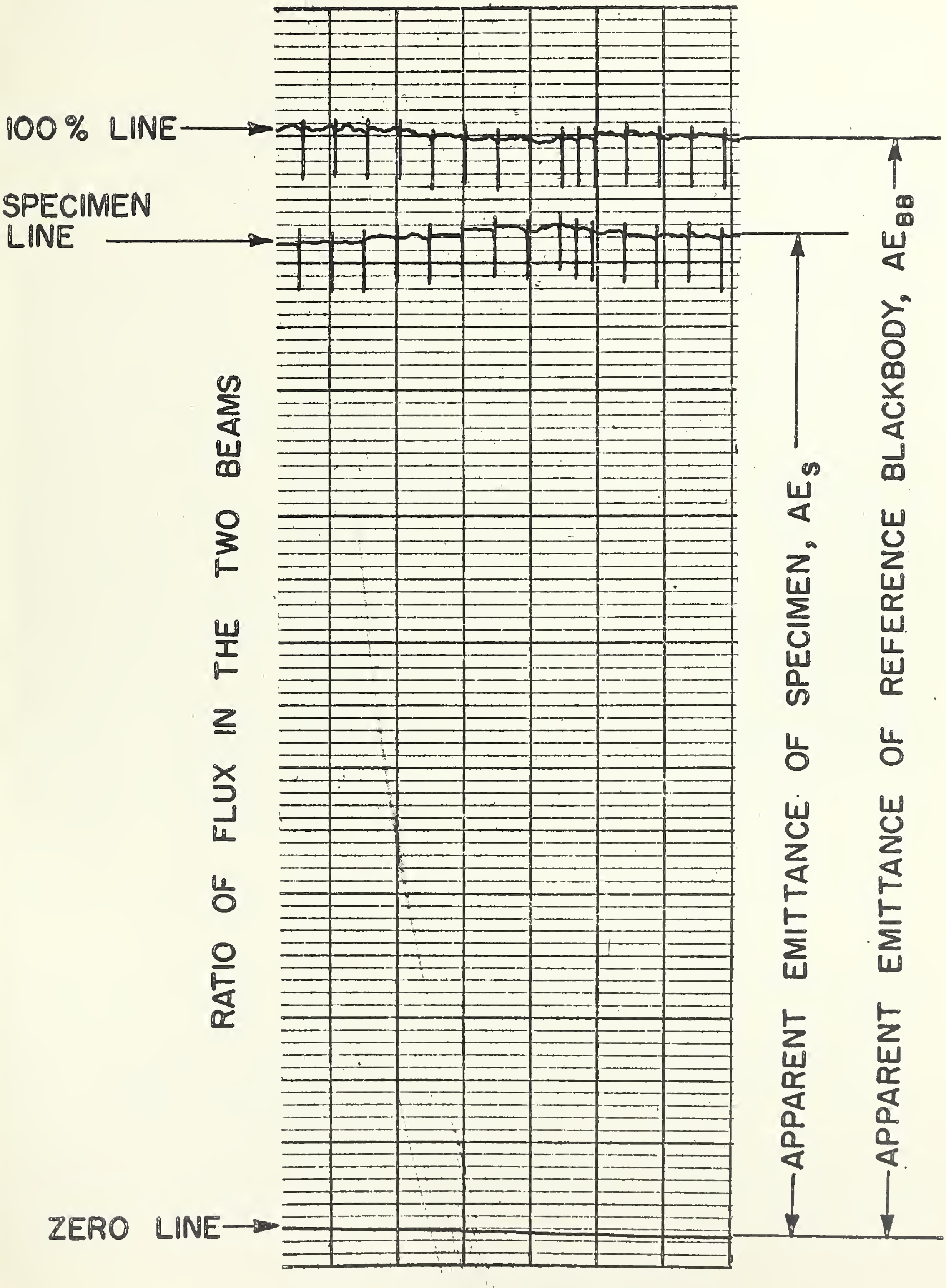

*
TAPE PLAYBACK
ZERO CONTROL
AMP.
I_0
"100%"
BLACK BODY INPUT SIGNAL
I_c
"100%" CONTROL
AMP.
NOTE
DASHED LINES SHOW SPECTROPHOTOMETER
* FOUR TRACKS
SPECIMEN SIGNAL
I_s
RECORDING POT.
SHAFT A/D
DIRECTION FLIP-FLOP
REVERSIBLE COUNTER
DISPLAY
MOTION SWITCH
DRUM DIAL
SHAFT A/D & COUNTER
ACCUM. SELECTOR
ACCUM.
PUNCHED TAPE READER
PUNCH SELECTOR
TAPE PUNCH

Figure 7. Section of recorder chart containing "100% line". "specimen line" and "zero line." Emittance is computed manually as the ratio of the apparent emittance of the specimen divided by the apparent emittance of the reference blackbody furnace, mathematically

$$E = \frac{AE_S}{AE_{BB}}$$



100 % LINE
SPECIMEN LINE
RATIO OF FLUX IN THE TWO BEAMS
APPARENT EMITTANCE OF SPECIMEN, AE_S
APPARENT EMITTANCE OF REFERENCE BLACKBODY, AE_{BB}
ZERO LINE

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D. C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research. Crystal Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Polymers. Macromolecules: Synthesis and Structure. Polymer Chemistry. Polymer Physics. Polymer Characterization. Polymer Evaluation and Testing. Applied Polymer Standards and Research. Dental Research.

Metallurgy. Engineering Metallurgy. Microscopy and Diffraction. Metal Reactions. Metal Physics. Electrolysis and Metal Deposition.

Inorganic Solids. Engineering Ceramics. Glass. Solid State Chemistry. Crystal Growth. Physical Properties. Crystallography.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials. Metallic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering Laboratory. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

CENTRAL RADIO PROPAGATION LABORATORY

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Soundings Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

RADIO STANDARDS LABORATORY

Radio Physics. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time-Interval Standards. Millimeter-Wave Research.

Circuit Standards. High Frequency Electrical Standards. Microwave Circuit Standards. Electronic Calibration Center.

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